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ENERGY RESOURCES

Trends and salient issues in energy resources

Report of the Secretary-General

SUMMARY

This report presents a broad and long-range view of the future production and use of energy. Its aim is to be comprehensive rather than detailed, and to provide a context for the Committee's deliberations on specific energy problems and issues. Energy developments in developing countries are given particular attention.

The future use of energy on a global basis is considered first (sect. II). The object of the section is not to project energy demand but to explore those factors influencing the future intensity of energy demand. Among such factors, the product composition of aggregate output will probably be conducive to a reduction of energy intensities in the developed countries in the years ahead, whereas the same factor will likely result in higher energy intensities in the developing countries. Both groups will benefit from the many opportunities for lowering energy intensities offered by technological change, and both will be able to reduce the intensity of energy use through the elimination of simple waste of energy, in particular, by a closer matching of form of energy applied to form required by end-use.

* E/C.7/1991/1.

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Section III deals with the supply side of the energy equation. Conceptually all fuels and energy forms are included; in terms of individual treatment, only the chief fossil fuels (oil, natural gas, and coal) and those energy sources in which the Economic and Social Council expressed specific interest in resolution 1989/6 could be discussed in detail, due to space limitations. Here too, the object of the section is not projection but rather investigation of the potential, constraints and realistic prospects for the actual exploitation of the various energy sources.

The role of public policy in energy affairs is discussed in section IV. The close relationship between energy policy and environmental policy is treated first. Free competitive markets are considered as devices for implementing the ideal of economically efficient production and use of energy. Cases of market failure and the possible policy response to such cases are discussed. Negative environmental effects of energy production and use - in particular, the global warming impact of the generation of greenhouse gases - are seen as examples of market failure in the energy field. National and international policy towards expanding energy production capacity in developing countries is taken up as a second major policy focus. The main obstacle to such expansion is identified as mustering the requisite financing. Efforts to increase the cash flows of energy enterprises in these countries, development of local capital markets, resource to foreign direct investment and intensification of the activities of the national and international development agencies are each given explicit consideration as remedial measures to the imbalance between investment required and financing forthcoming. Finally, strengthening economic and technical co-operation among developing countries is posited as an important aspect of energy policy for many individual developing countries.

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INTRODUCTION

1. This report presents a broad and long-range view of the future production and use of energy. Its goal is to provide a context or broad background for the Committee's deliberations on more specific energy-related questions. Since energy is to be given priority consideration by the Committee at its twelfth session, the presentation of such an overview at the current session has seemed especially appropriate.

2. It is inevitable that any study which assays an overarching view of energy affairs will be led into consideration of related fields. Of the many areas tangential to energy, only one is explored in this report - the natural environment. The relationship between energy conversion and environmental integrity is so close as to render the two subjects virtually indistinguishable from a policy perspective. This is a view shared by most members of the Committee, as revealed by the discussions at the eleventh session.

3. The report places considerable emphasis on the importance of enhancing the efficiency of energy production and use. This is also a topic which the Committee stressed at its eleventh session, and one which has come to dominate professional and public discussions of energy affairs. It is closely related to the environmental question.

4. Conceptually, the report covers all fuels and energy forms - everything from fuelwood to fusion - and, all stages of energy conversion - from extraction of fuel minerals from the earth to final use by consumers and enterprises. The analysis is conducted at the global level, but the energy needs, resources, and prospects of developing countries are given particular attention. Its time horizon extends through the first two decades of the next century, up to approximately the year 2020.

5. The primum mobile of energy affairs is its final use by enterprises as a factor of production and by individuals as an object of direct consumption. Such final conversions form the subject of section I of the report. The object of the section is not to predict the future levels of energy use but rather to discuss certain factors which will influence the future intensity of energy use (i.e., energy use per constant dollar of gross domestic product) in important ways. Accordingly, likely trends in the sectoral composition of aggregate economic output in industrialized and developing countries are treated, sources of waste in energy use are identified and new developments in energy efficent goods are considered.

6. Section II deals with energy production, namely, the extraction of fuels from the earth and the energy conversions (primary and intermediate) which precede the final conversions into end-uses. The discussion is all-embracing, first identifying the ultimate sources of energy available to mankind, then reviewing the existing stocks of energy carriers, such as fossil fuels and finally surveying the many technologies available for drawing upon renewable energy flows. Once again, the object is not prediction but rather assessment of possibilities as revealed by the magnitudes of energy stocks and flows, and the possible constraints to their utilization in the form of costs of production and technological bottle-necks.

7. Energy policy forms the subject of section III. Emphasis is placed on the link between such policy and environmental policy. Competitive markets are identified as the most frequently employed institutional device for seeking economic efficiency in energy production and use. Policy in cases of market failure is discussed and applied to energy-related environmental problems. A fairly lengthy treatment of the problem of augmenting energy production capacity in developing countries is provided, and the possibilities for economic and technical co-operation among developing countries are discussed.

8. Because of the request of the Committee at its last session that documents for the twelfth session be distributed three months in advance the report was substantially completed before the onset of the current crisis in the Persian Gulf. However, the crisis reinforces one of the major conclusions of the study, namely, that in the design of long-run energy policy, major emphasis needs to be given to augmenting the efficiency with which energy is utilized.

I. THE FUTURE INTENSITY OF ENERGY USE

9. Energy use is often characterized as energy "consumption", although energy is never consumed (nor produced for that matter) in any ultimate physical sense. What is termed energy consumption (or production) is simply the conversion of energy from one form to another. Every such conversion involves a cost in terms of a quantity of energy (ordinarily in the form of heat) forever lost to the subsequent pursuits of man. Although the waste of energy constituted by conversion losses can be mitigated, it can never be entirely eradicated.

10. The energy conversions discussed in this section are final conversions - they perform directly useful work. These final uses should be distinguished from intermediate ones, in which energy in one form is merely changed to a more convenient form (as a preparatory step to the performance of work), for example, from heat to electricity in (thermal) electricity-generating plants. The latter are important too and are discussed in section II. Table 1 shows the distribution of final (commercial energy use in the production of goods and services and as directly consumed in 1985, the last year for which data are available for all the country groups shown.

11. From a purely logical point of view, there are four generic ways of reducing energy use in a country:

(a) Cut aggregate production of goods and services or direct consumption of energy (and, thereby, standards of living) by whatever degree is necessary to achieve some targeted lowering of total energy conversion;

(b) Maintain aggregate output <u>in toto</u> but shift its composition towards less energy-intensive activities;

(c) Maintain output constant, in total and in composition, but substitute capital (and, perhaps, labour) for energy within the mix of factors of production;

Table 1. Distribution of final (commercial) energy conversion in 1985

(Percentage)

	Developed market economies	Developing countries	Eastern Europe and USSR
In production of goods and services:			
Industry	34.3	48.4	54.0
Transportation	29.6	21.9	13.6
Non-energy uses	3.1	2.2	3.3
Agriculture	1.6		
Commercial a/	12.3	27.5	29.0
Direct consumption:			
Residential	19.2		
Total final conversion:	100.0	100.0	100.0

Note: Figures may not add to totals because of rounding.

Sources: For developed market economies - OECD, Energy Balances 1970-85, p. 19; to developing countries and Eastern Europe and the Soviet Union - OECD, World Energy Statistics and Balances 1971-1987, various pages.

a/ Includes wholesale and retail trade, government and other public service, real estate and insurance. For developing countries and Eastern Europe and the Soviet Union also includes agriculture and residential.

(d) Maintain output constant but eliminate simply physical waste of energy. (No substitution among factors is required because the energy in question has zero marginal product. An example might be turning off lights not in use.)

12. Although the first method (a) is a logical possibility it is not a practical one; presumably, no Government would contemplate deliberately reducing gross domestic product (GDP) or living standards simply in order to lower energy conversion in the country. This suggests that to discuss energy use in a society in a meaningful way, it is necessary to consider it in relation to some amount of aggregate output or some level of living standards. The measure of energy use suggested by such thinking is called the "intensity" of energy conversion and is defined as the amount of energy used per (constant) dollar of aggregate output. 1/ In recent years, such intensities have fallen in the developed market economies (from about 3.6 barrels of oil equivalent per $1,000 of GDP in 1973 to 2.7 barrels

of oil equivalent per $1,000 of GDP in 1986) and in Eastern Europe and the Soviet Union (from 9.5 barrels to 8.3 barrels over the same period). They have risen in developing countries, however, (from 3.2 barrels in 1973 to 3.9 barrels in 1986). Methods (b), (c) and (d) all result in a lowering of the energy intensity of aggregate production. Each will be discussed in turn in the subsections which follow.

A. Effects of shifting output patterns

13. Shifts in the product composition of aggregate output will be one of the most important factors influencing the energy intensity of the production of goods and services over the next three decades.

14. In the developed market economies, for example, the likely continuation of recent trends in product composition will work in the direction of a lowering of the energy intensity of output. The long-run sequence of economic development in the industrialized countries has been from agriculture to industry to services production. This is shown in the pattern of employment over time. For example, in Sweden employment in agriculture fell from over 70 per cent of the labour force in 1870 to about 5 per cent in 1980. Meanwhile, employment in industry rose from 9 per cent in 1870 to a peak of 45 per cent in 1960, declining thereafter to 35 per cent in 1980. Over the whole 1870 to 1980 period, the fraction of the labour force employed in services production climbed virtually continuously accelerating at about the same time that the share of labour devoted to industry began to fall. Similar trends have been experienced in most developed countries. Reflecting the average energy intensities of production in the three sectors, these shifts in product composition contributed to the long-term rise, then - in the last decade or so - to the decline, in the overall energy intensity of production in the developed countries.

15. Accompanying the recent trend towards relative substitution of services for goods in aggregate production has been a shift within industry from heavy industries (such as mining, construction, and basic materials processing) to fabrication and finishing. During the 1970s in the United States, fabrication and finishing activities grew by over 4 per cent per year, whereas basic materials processing rose by only 3 per cent per year, and mining and construction by only a little over 1 per cent annually. The significance of these disparate trends lies in the fact that, although early in the decade fabrication and finishing represented 50 per cent of value added in industry, it accounted for only 10 per cent of energy employment in the sector. On the other hand, basic materials processing, while contributing only 25 per cent of industrial output, employed over 70 per cent of the sector's energy input. Hence, the higher growth rate of fabrication and finishing manufacturing relative to that of heavy industry tended to lower the energy intensity of industrial output, specifically, and - with the ongoing trends towards services - to reduce the energy intensity of production of goods and services in general. Similar trends, and consequences, have been observed in the other developed market countries. 2/

16. Recent research suggests that the swing from basic materials processing to fabrication and finishing in the developed market economies may be due to simple saturation in the use of such materials in these countries. Per capita consumption of a broad range of basic materials (steel, cement, paper, aluminium, ethylene, ammonia, etc.) stopped expanding in the Federal Republic of Germany, France, the United Kingdom and the United States during the 1970s. 3/

17. The situation in developing countries is quite different. At present, the industrial sector dominates the distribution of value added by productive sector in every broad geographic region of the developing country group. It is important to realize that what is reflected in the prominence of industry in these countries is the weight of mining activities, not manufacturing. The recent historical trend in the developing countries has been a relative shift away from both agriculture and mining to basic materials manufacturing. To the extent that the transition has been specifically from agriculture, the effect has been to raise the energy intensity of aggregate output in the group. This changeover in product composition will almost certainly continue for developing countries as a whole over the next few decades, raising the energy intensity of aggregate production in these countries.

B. Technological opportunities to lower energy intensities

18. This subsection will discuss specific technological opportunities for the reduction of energy intensities. In the production of goods and services, possibilities in the industrial, transportation, and commercial sectors will be treated; in the direct consumption of energy, opportunities in residential use of energy will be the focus of attention. The objective of the subsection is to chart the limits of what is physically possible in the way of reducing energy intensities. The necessary - but subsequent - question of what is economically efficient in this regard is treated in section III.

Industrial sector

19. The industrial sector (manufacturing, mining and construction) alone accounts for roughly one third to one half of all energy use, depending on the country group (see table 1). Thus, if the overall intensity of energy use in global production is to be lowered, the industrial sector must figure prominently in energy savings efforts. Fortunately, the opportunities for reducing energy intensity in the sector are large.

20. Changes in industrial processes themselves frequently offer several-fold reductions in energy intensity. A good example can be found in the steel industry. In theory, utilization of a 50-50 mixture of ore and scrap iron necessitates an energy input of about 3.9 gigajoules (GJ) 4/ per tonne of output. In practice, steel-making methods, using 50-50 mixtures, usually require from 20 to 30 GJ of energy. However, steel manufacturing processes which sharply reduce actual energy input requirements have recently become available. For example, the Plasmasmelt process demands only 8.7 GJ per tonne of steel and the Elred technique only 11.7 GJ. 5/

21. Variations in the products of industry also offer possibilities for reducing the energy intensity of the sector. In some cases, changes in the design of final products are conducive to this goal. For example, design changes that reduce the weight of a product, extend its useful life or substitute recycleable for non-recycleable materials can reduce its energy component. At the primary level, entirely new materials, such as new kinds of cement, which have low energy intensities are under development.

22. Finally, improvements in the physical efficiency of conversion devices utilized in industry will lower the energy intensity of the sector. The possibilities for improving the physical efficiency of conversion devices in industry are legion: among others, waste heat can be captured and used, furnaces can be better insulated and radiation reflectors installed. On an energy savings-per-application basis, enhancements of conversion devices offer less dramatic results (perhaps 25 to 50 per cent of energy employed) than do changes in the basic processes of industry or in the design of industrial products. Nevertheless, given the ubiquity of conversion devices, in toto, improvements in these devices can have a major impact on energy intensity of industry. 6/

23. Probably the most important case here lies in the area of drive shaft power. It has been estimated that from 28 to 60 per cent of electricity used in all drive shaft applications in the United States could be saved through improvements in electric motors and ancillary equipment. Assuming that these percentages are applicable to electricity employed in drive shaft applications in industry, specifically, from 3.5 to 7.5 per cent of all industrial energy employed in this country could be conserved. 7/

Transportation sector

24. After industry, the transportation sector seems to offer the most fruitful area for reduction of energy intensity. Automobiles and light trucks, which account for over 60 per cent of all oil used in transportaton in the developed market economies, present possibilities for major improvements in energy conversion efficiency. Currently, the percentage of chemical energy in fuels which is finally converted to mechanical energy at the wheel of these vehicles is typically only in the low teens. However, a shift to advanced diesel engines, efforts to lower air drag and rolling friction, substitution of continuously variable transmissions, weight reduction and idle-off controls (in purpose like those applicable to electric motors) can raise the fuel economy of automobiles anbd light trucks from the present, roughly, 10 litres per 100 kilometres to perhaps 3 litres per 100 kilometres in the years ahead. 8/ The same sorts of improvements can double the productivity of heavy trucks (in terms of tonne-kilometres per litre).

Commercial sector

25. The commercial sector is a catch-all term for a wide variety of value-adding services other than transportation. Virtually all energy use in the sector is for space conditioning (heating and air conditioning), and thus efforts to reduce the energy intensity of the sector must be directed towards improving the use of energy in buildings.

26. New commercial buildings are, broadly speaking, more efficient in energy conversion than those constructed in the past; yet most are far from optimal in this regard. Although further improvements in the energy efficiencies of the structural shells of commercial buildings are certainly possible and desirable, improved energy management in existing buildings appears to offer grater scope for reducing the energy intensity of the commercial sector. Such simple management steps as setting back thermostats at night and exercising a more careful control of air flow thorugh buildings typically result in heat savings of up to 30 per cent with little or no capital cost.

27. By and large, the opportunities for reduction in the energy intensity of production of goods and services do not vary markedly - in a qualitative sense - from developed to developing countries. Possibilities in industry, specifically, will become more important quantitatively in developing countries as these countries become larger producers of basic materials in the decades ahead.

Residential energy

28. Space heating dominates residential energy utilization in all member countries of the Organisation for Economic Co-operation and Development (OECD) and will be the focus of efforts to raise residential energy productivity in the future. House shells offer many opportunities for improvements in energy conversion efficiency. The possibilities of new construction are represented by, for example, the Northern Energy Home in the United States (presenting space heat requirements of only 15 kilojoules per square metre per degree-day) and the Faluhus house (version 2) of Sweden (requiring only 17 kilojoules per square metre per degree-day). These figures compare with average heating requirements of the (then) current housing stock in the United States and Sweden of 160 and 135 kilojoules per square metre per degree-day, respectively. 9/ Many opportunities exist for energy savings from the retrofit of existing dwellings. Individually, such energy enhancements are less spectacular than those associated with new residences. Nevertheless, because of the relative weight of old structures vis-à-vis that of new ones in the housing stock, energy improvements in the former can be very important.

29. Residential consumption of energy is also very important among developing countries, although cooking takes precedence over space conditioning, and traditional fuels (fuelwood and organic wastes) over commercial ones. 10/ The type of stove used for cooking is an important factor influencing energy conversion efficiency. In actual practice in developing countries, per capita annual energy consumption for cooking runs as high as 100 times greater for wood-burning stoves than for petroleum product-burning ones. After earlier disappointing results, efforts to promote the substitution of more efficient stoves (of both types) seem to be gathering momentum more recently. In addition to featuring more physically efficient and lower-cost stoves, current efforts along these lines seem to incorporate a heightened awareness of such practical considerations as convenience and respect for traditional food preparation practices.

C. Reducing energy waste

30. The cheapest way of reducing energy intensities in a society is to eliminate simple physical waste of energy. Probably the largest occurrences of such waste arise through the non-observance of a basic principle of energy conversion, namely, that energy should be applied originally in a form that matches what is actually required by the end-use. This matching principle pertains both to energy's use as a factor of production and as an object of consumption.

31. Often, violations of the principle take the form of applying fuels of high energy potential to end-uses of only low energy needs. As expressed in one study,

> "Currently much heat of high thermodynamic availability is wasted because it is used for a low-temperature application which could readily be satisfied with low-temperature heat. Fuels with the capability of a flame temperature of 2000+°F are burned with the ultimate objective of making hot water, for example. A solar process heat system should be designed to satisfy the needs of a process and not merely to substitute for the current method of providing heat." 11/

32. Another departure from the principle of properly matching means to ends in energy use involves choosing a form of energy which requires multiple conversions before reaching the form required by the particular end-use in view. As noted earlier, there are two products of every energy conversion: a certain quantity of useful energy and a residuum of wasted energy (ordinarily in the form of heat). Hence, ceteris paribus, the fewer energy conversions to precede a given final conversion (the turning of a wheel, the lighting of a lamp) the less energy wasted. For example, if the object is to raise the air temperature in a room, it might be a poor choice to do so by converting heat to electricity (in a thermal electricity-generating plant), and then electricity back to heat (in an electric room heater), if a direct (single conversion) source of heat was available to be applied to the room.

33. Concern for applying energy forms which are appropriate to the final task to be performed is not motivated by respect for abstract thermodynamic elegance. The physical waste of energy inherent in violations of the matching principle has serious consequences for the cost of the energy finally delivered to end-uses. Energy mismatching affects costs in two ways: more energy is converted in toto than is needed for the end-use under consideration, thereby raising the cost of final products (or the cost of direct energy consumption), and the unit costs of supplying the energy form applied may exceed those of the form required.

34. Cost implications are especially serious in the case of applying electricity to end-uses which are not inherently electrical in nature. Certain important energy applications (space and water heating, and drive shaft power among the more important) do not necessarily require energy in the form of electricity; yet electricity is often utilized in these end-uses. Electricity has important advantages as a form of energy for many end-uses: it is convenient, clean, relatively safe and easily controllable. It is, however, in most geographic areas a relatively expensive form, especially in terms of capital costs. Ultimately, of

course, economic criteria - not thermodynamic ones - must govern the choice of energy forms to be applied to particular end-uses. Nevertheless, choices which reflect a conscious policy of avoiding the physical waste of energy will - generally speaking - be more often validated by economic rationality than ones which are wantonly profligate in the utilization of energy.

D. Energy intensity and energy efficiency

35. Much of the practical policy action of Governments in the energy field over the last two decades has been devoted to reducing energy intensities. Given the dramatic increases in the relative price of oil in 1973-1974 and 1979-1980, it is understandable that subsequent declines in energy - and, particularly, oil - intensity have been interpreted, prima facie, as movements towards a more efficient use of energy. Yet it is well to remember that energy intensity and energy efficiency are not synonymous.

36. Every possible level of energy use in a particular employment has associated with it an energy intensity, that is, the ratio of energy to the (real) value of economic output. However, only one level of energy use is economically efficient, namely, the level at which the value of the social marginal product of energy is equal to its social marginal cost. Such an allocation is efficient in the sense that, if applied in every employment, it would maximize the value of aggregate economic output resulting from the use of a given quantity of energy.

37. Striving for economically efficient energy use, however, has nothing to do necessarily with minimizing energy intensity. If, at the going rate of employment of energy, social benefits exceed social costs, then the rate of energy use should be increased until such benefits fall to the level of costs. The consequence of such a change in employment may be to raise or lower the intensity of energy use; as a purely logical matter it is impossible to say in general. (A similar conclusion is reached if the original situation is one in which social benefits are less than social costs.)

38. The practical relevance of this cautionary note is that much of the developing world will experience rising energy intensities in the future, and these should not necessarily be interpreted as movements away from efficient energy use. If many developing countries find a comparative advantage in basic materials processing in the years ahead, as observed earlier in this section, then their energy intensities will rise. Such rises could be consistent with the economically efficient employment of energy.

II. AN OVERVIEW OF WORLD ENERGY SUPPLIES: POTENTIAL AND PROSPECTS

39. Mankind can draw upon enormous resources of energy derived from processes occurring in the sun, moon and earth itself. These amount to at least 1,600 terawatt-years 12/ (TWY) of energy in the form of (non-renewable) stocks of fossil fuels and nuclear materials, and at least 120,000 TWY of energy every year as a

(renewable) flow of solar, tidal and geothermal energy. In view of the fact that annual human energy use is only about 11 TWY per year (all energy forms, for all purposes), it is clear that mankind does not face any absolute physical shortage of energy. It does confront the challenge of converting this enormous theoretical potential into a practical potential.

40. Assessment of the magnitude of this practical potential and the prospects for realizing it form the subject matter of this section. Given the number of distinct forms and fuels, it is impossible to give separate treatment to each in a document of this length. Only the most important fossil fuels (petroleum, coal and natural gas) and those fuels and renewable energy flows in which the Economic and Social Council in its resolution 1989/6 expressed a particular interest (natural gas, heavy crude, tar sands, oil shale and geothermal resources) are accorded individual consideration. Probably the most important omission is nuclear energy. Given the fact that nuclear materials other than uranium may come into wider use in the future and that uranium itself can be utilized in various nuclear cycles (once-through, with reprocessing, in breeder reactors, etc.), it is difficult to even give a meaningful figure for the energy content of the world's nuclear materials. Rapid technological change in the field also militates against a treatment of nuclear energy which is both brief, as space limitations demand, but also minimally thorough. For an energy source which does receive explicit treatment, the outlook for its technological maturation, its costs of production and the constraints peculiar to it are investigated. Such an examination should provide the basis for an appreciation of the potential of the energy source and the grounds for a realistic assessment of the prospects for that potential being realized.

A. Conversion of the earth's energy stocks

41. In spite of their rather small energy content, compared to the enormous quantity of energy which flows from the sun over the course of only a single year, the energy stocks of the earth provide mankind with at least four fifths of its current energy supply and will remain indispensable for the foreseeable future.

42. The energy stocks of the earth appear as chemical or nuclear energy contained in matter. The materials holding this energy - so-called energy carriers or fuels - must be first extracted from the earth and then processed in various ways (depending on the energy carrier in question) to yield particular products. The energy contained in these products is then available for final conversions as described in the preceding section. Two broad classes of energy carriers comprise the earth's energy stocks - fossil fuels (mainly petroleum, coal and natural gas) and nuclear materials (today overwhelmingly uranium).

Petroleum (including heavy and extra heavy oil)

43. Petroleum - crude oil and natural gas liquids (NGL) - has become the world's leading source of energy. The advantages of petroleum over other fossil fuels are straightforward: it is, uniquely among energy carriers, a source of liquid fuels, heat and - if need be - of electricity, and it is easily transportable. The proven

recoverable reserves of crude oil and NGL amounted to about 123.6 billion tonnes, or 16.5 TWY of energy, at the end of 1985. These are highly concentrated geographically with about two thirds of the total in the Middle East. Ultimately recoverable reserves (proven plus estimated additional reserves), are usually stated at about 275 billion tonnes. 13/

44. It seems clear that the technology of petroleum production will not act as a limiting factor in turning this resource potential into solid production capacity. Indeed, the technology of petroleum production has experienced a long, successful process of development, one which is still advancing rapidly at each of the major stages of oil production - exploration, production proper (extraction of oil from the earth) and refining. In particular, great strides have been made in exploration through the employment of three-dimensional seismic surveys, made possible by digital computers. Also, entirely new exploratory concepts and theories of petroleum formation and migration have already had dramatic results in terms of discoveries and hold great promise for the future. At the production stage, the broadening application of the computer and a host of improvements in drilling equipment have increased the productivity of recovery methods, and steady progress across the whole field of production techniques and methods can be anticipated in the future. Horizontal drilling will be important in extending the useful lives of known fields. Finally, various developments in refining technology will raise the yield of light, more valuable products from a barrel of crude oil. Thus, simple know-how and the capability to manufacture the requisite equipment will not act as a constraint on future oil development.

45. The relationship between the costs of oil production and the price of oil may, however, seriously delay the time at which certain oil accumulations are brought into operation. There is a continuum of such costs, ranging from those of many fields in the Middle East, which are easily assessable and prolific, to those of fields in the Arctic, which are geographically isolated and present harsh working conditions. The expected (long-run average) price of oil - heavily influenced by recent actual prices - acts as a dividing line in this continuum, in effect, separating undeveloped oil into two categories: that which is considered to be economically developable given current price expectations and that which is not. Thus, as the price of oil (and, therefore, price expectations) rises and falls over time, the amount of oil deemed recoverable also changes.

46. Much of the oil falling into the "estimated additional recoverable" category, over one half of all recoverable oil, is subject to very high costs, compared to the costs which pertain to oil already in use. Such oil lies in fields exhausted to primary production methods but amenable to enhanced recovery techniques, or in basins which are deep offshore or in the Arctic. Table 2 presents estimates of the costs of production (including investment costs) of various classes of such oil. The different kinds of oil form a likely developmental sequence - ordered by costs of production - from crude oil amenable to enhanced recovery (requiring an investment of roughly $20,000 per incremental barrel per day), to deep offshore oil (at $30,000 per barrel per day), to Arctic oil and extra-heavy oil (at $40,000 per barrel per day).

47. Broadly speaking, there are two theories on the rate at which high cost oil will be developed and brought into production in the future. There is general agreement that the excess production capacity of the world oil industry, which is heavily centred in the Middle East, has been considerably eroded in recent years and will disappear altogether in the present decade. At that point, there are two possibilities, adherence to one or the other defining the two schools of thought on the question of rate of exploitation of deep offshore and Arctic oil. One possibility is that the attempt to expand production capacity in the Middle East during the 1990s will encounter significantly higher investment costs. The latter will translate into higher total production costs and higher oil prices, opening the door for development of high cost oil provinces and actual production of such oil early in the next century. The other possibility is that the next great wave of capacity expansion in the Middle East will be executed at roughly constant costs (in real terms); no great upward pressure will be exerted on oil prices because of cost increases; and, development of high cost oil will remain simply too expensive. Thus, the exploitation of sources of oil alternative to those of the Middle East would be precluded by the normal operation of the market until well beyond the turn of the century.

48. The first point of view seems to be the conventional one within the oil industry itself. Estimates of the possible production volumes of different kinds of high cost oil in 2010 - based upon this sort of thinking - are given in table 2. Two figures are given for each type of oil: a lower, representing output on a "trend" hypothesis, that is, incorporating the effects of normal technological enhancements and gradual cost declines; and a higher, portraying the effects of technological jumps, which would greatly lower costs. The range given, 250-420 million tonnes, could represent 10 to 17 per cent of total oil production outside of the Soviet Union in 2010.

Table 2. Production costs, investments, and possible production in 2010 of certain classes of oil

	Production costs ($/barrel) a/	Required investment ($/barrel/day) a/	Possible production in 2010 (millions of tonnes/year)
Light and heavy oils recoverable by enhanced recovery methods:			120 - 200
Steam flooding	12 - 30	10 000 - 30 000	
In situ combustion	12 - 30	10 000 - 30 000	
Polymers	12 - 24	12 000 - 37 000	
Miscible gas/CO_2	12 - 36+	12 000 - 30 000	
Surfactants	24 - 61+	18 000 - 37 000	
Deep offshore oil	12 - 36+	18 000 - 43 000	75 - 120
Arctic oil	18 - 36+	30 000 - 55 000	30 - 60
Extra-heavy oil	24 - 36	37 000 - 49 000	25 - 40
Oil from tar sands	30 - 55	37 000 - 67 000	20 - 40
Oil from shale	49 - 73	61 000 - 85 000	10 - 20
Synfuels:			
From coal	73 - 122	97 000 - 145 000	
From natural gas	49 - 85	85 000 - 120 000	
From biomass	61 - 122	73 000 - 120 000	
Memo: oil already developed -			
Middle East	1.50	600 - 3 700	
Elsewhere	10.00	3 700 - 15 000	

Source: Adapted from N. Boy de la Tour, J. L. Gadon, and J. J. Lacour, "New Oil: What's in the Future?", Energy Exploration and Exploitation (Barking, U.K.: vol. 4, No. 6, 1986, Elsevier Applied Science Publishers).

a/ 1985 costs in 1990 United States dollars.

Oil from tar sands

49. Tar sands are essentially crude oil which has undergone extensive chemical and physical changes over long periods of time. They have a viscosity of over 10,000 cP, which makes them completely immobile at normal temperatures and pressures and necessitates extraction by mining rather than by drilling, as in the case of crude oil. Tar sands yield two products: bitumen, which can be used directly in asphalt plants or, more importantly, a synthetic crude oil, which results from upgrading bitumen and which serves as a refinery feedstock just as natural crude oil.

50. Proven recoverable reserves of oil amount to about 70 billion tonnes (93 TWY of energy). Estimates of total recoverable reserves (proven plus estimated additional) range as high as 140 billion tonnes but are extremely uncertain. 14/ Most of the world's tar sands occur in Canada, with about 75 per cent of the world's resources, and in the Soviet Union, with about 22 per cent of the world total. The remaining 3 per cent is distributed among 18 other countries. Almost 99 per cent of the tar sands deposits occur in a few giant deposits (those containing more than 1,000 million barrels of bitumen in place) in Canada, the Soviet Union, the United States, Nigeria, Angola and Chile. Many other countries have unevaluated tar sands deposits, but most of these occurrences appear to be small. 15/ At present, only Canada has a full-scale tar sand industry, but various research, demonstration and pilot plant activities exist elsewhere. A few of the unevaluated deposits may someday be of commercial interest if the technology currently being developed proves to be transferable, if the economics of tar sand utilization improve and if local environmental problems associated with tar sand production can be overcome.

51. Two major problems may inhibit the development of tar sands in the future. One has already been referred to, namely, the environmental impact of tar sands mining. Equally importantly, costs of production of $30 to $55 per barrel of syncrude and needed investments of $37,000 to $67,000 per incremental barrel per day of production capacity may prevent the evolution of true tar sands industries outside of Canada (see table 2). As in the case of high-cost crude oil, much depends on the price of oil. If the price of oil does rise in real terms in the late 1990s, then in the year 2010 roughly, volumes of syncrude from tar sands ranging from 20 to 40 million tonnes per year may eventuate (see table 2). Once again, the extremes of the range correspond to two scenarios: one in which gradual technical change and cost reduction occurs; the other in which technological breakthroughs reduce costs sharply.

Oil shales

52. Proven recoverable shale oil reserves have been estimated to be approximately 10 billion tonnes of oil (13 TWY of energy) out of a total recoverable quantity of, perhaps, 400 billion tonnes. 16/ The latter figure, especially, is subject to great uncertainty. Oil shales have been identified in some 40 countries, but no exhaustive resource estimates have been made so far. Roughly one half of the shale oil deposits in place (as opposed to recoverable) appear to lie in the United States, with perhaps another 10 to 15 per cent in each of Brazil, China and the Soviet Union. 17/

53. Given the fact that the kerogen in the shales is a solid, mining methods must be utilized to extract the shale from the earth. This is followed by thermal methods of extraction of shale oil. A preliminary refining of the shale oil is then normally performed at the extraction site to produce a crude oil refinery feedstock. However, in a few countries, oil shales are directly combusted for electricity generation. For example, in the Soviet Union, in the Estonian Soviet Socialist Republic, two large power stations operate in this manner.

54. Like other primary energy conversion technologies which rely upon mining in the ore extraction phase (conventional coal, tar sands, coal liquefaction and gasification), shale oil production is hampered by severe environmental consequences. Surface disfigurement (or the cost of rectifying it) and the sheer volumes of solids and water which must be disposed of are daunting problems.

55. Total costs of production of refinery feedstock from oil shale runs from about $50-$70 per barrel and involve investments of about $60,000-$85,000 per incremental barrel per day (see table 2). It seems unlikely, given the cost advantages of crude oil and oil from tar sands, that oil shales will be extensively developed until far into the next century, barring a technological breakthrough that would greatly reduce costs or a major rise in the price of crude oil, which is generally regarded to be permanent.

Coal

56. Coal is the world's most widely available fossil energy source, with proved recoverable reserves of about 1,075 billion tonnes, 18/ equivalent to 1165 TWY of energy. At the present world-wide rate of consumption, and with existing technology, the economically recoverable resource of coal would last several hundred years. Some 75 per cent of total proved recoverable reserves of hard coal occur in just three countries, China (600 billion tonnes), the United States (113 billion tonnes) and the Soviet Union (104 billion tonnes). At present these countries produce about two thirds of the world's hard coal. Also, in the case of lignite, some 60 per cent of the proved recoverable resources are concentrated in these three countries. 19/ Most of the incremental coal production capacity is expected to come from the traditional major producers, mainly China, the United States and the Soviet Union, but also South Africa, Australia, Canada, India and Poland.

57. To increase the use of coal in the developing countries large capital investments in extractive, consuming and transport facilities will be required. According to a 1985 World Bank estimate, China will have to invest $43.5 billion in mining equipment and services to achieve its goal of producing 1.2 to 1.4 billion tonnes per year of coal by the year 20000. 20/ China's total run of mine coal production in 1985 was 840 million tonnes. 21/ Thus, the investment for the incremental production will be about $77 per tonne. In India, the investment required for an improvement project for two large-scale, open-cast mines, being carried out with World Bank assistance, is about $48 per tonne, based on an estimated capital requirement of about $477.5 million over a period of about seven years (1988-1994) for an incremental production of 10 million tonnes of coal. 22/

58. Further development work continues to improve the economic factors and reduce the environmental impact of direct utilization of coal. In the field of heat and electricity generation, emphasis must be on techniques ensuring high environmental acceptability without the need for expensive waste-gas cleaning installations. Technologies that may make significant contributions towards these aims are fluidized bed combustion systems, the integrated gasification combined cycle and the use of molten carbonate fuel cells.

59. In addition to technologies for the direct utilization of coal, gasification and liquefaction processes will continue to develop, as gas and liquid fuels are clean, easy to handle and transportable in pipeline systems. A variety of methods exists for coal gasification, and a number of these have been tested and found to be promising. Costs of production, in particular capital costs, are a major obstacle to commercialization (table 2). As a rule of thumb, medium British thermal unit (BTU) gas produced from coal will cost about three times the equivalent BTU cost in coal. Conversion to methanol will again double the cost, so that high BTU gas will cost six times the equivalent BTU cost in coal. 23/ Coal liquefaction technologies date back to the very early part of this century, and those technologies still form the basis for most processes being developed. However, costs remain very high.

Natural gas

60. Proved recoverable reserves of natural gas are about 109,000 billion cubic metres, that is the equivalent of about 100 billion tonnes of crude oil, or 125 TWY of energy. 24/ It is noteworthy that high gas reserves have been proved despite the fact that the main thrust of exploration efforts have been directed to the search for oil, rather than gas. Possibly, a great deal more natural gas will be discovered when exploration efforts are directed towards it. Also, natural gas reserves are almost always understated, and gas discoveries in remote areas are sometimes simply not reported.

61. Almost 38 per cent of the proven recoverable reserves of natural gas in the world is located in the Soviet Union (41,000 billion cubic metres). 25/

62. A growing number of developing countries, especially in Africa, have proven gas reserves which have not yet been fully developed. Others, as in the Middle East, have barely begun to exploit their considerable reserves. However, developing countries face major obstacles in expanding domestic gas usage, as the construction of pipeline and distribution networks is a costly process.

63. Iran, with about 13,800 billion cubic metres of proven gas resources, is exploring the possibility of pipeline exports to Central Europe, via Turkey, and to Asia, through Pakistan. Gas production in Iran will increase significantly with the rise in domestic consumption, as a huge gasification programme is under way. Domestic pipelines have been laid, and a gas processing plant with a rated capacity of 85 billion cubic metres per year has been inaugurated. 26/

64. In Africa, Algeria has embarked on a renovation and expansion of its gas production facilities, including natural gas liquefaction. It has agreed to a

one-third increase in the capacity of the existing trans-Med pipeline, and has directed marketing efforts to the western pipeline to Spain, via Morocco and Gibraltar. 27/ Elsewhere in Africa, Nigeria has begun building industrial and domestic markets, having started construction of a pipeline from the fields in the delta to Lagos, aiming for a market of 15 billion cubic metres per year. 28/ It is also proposing a $2.5 billion LNG export project to Europe. 29/

65. In the Asia and the Pacific region, natural gas production will continue to rise, especially from offshore fields. Owing to the vast distances in the region, gas is marketed mainly as liquid natural gas (LNG) rather than as pipeline gas. Indonesia, Malaysia, and Brunei Darussalam are the leading suppliers of LNG, soon to be joined by Australia's Northwest Shelf. There is more than sufficient capacity in these countries to meet considerable increases in world LNG demand. An international gas pipeline system in the region has been proposed, the Trans-ASEAN pipeline.

66. In Latin America, although several countries have increased their natural gas reserves substantially, development of these gas fields may be slow and difficult due to the long distances between fields and markets and the costs those distances imply.

67. A combination of public opposition to nuclear power generation and environmental issues has led to a proliferation of projects for natural gas-fired power plants. Also, natural gas is increasingly being used in co-firing in existing coal-fired boilers. Co-firing can be accomplished at a very low capital cost and with virtually no technological risk.

68. A new phase of natural gas utilization is materializing as technical progress is making it available as a motor transport fuel with relatively benign environmental impact. Methanol from natural gas is an attractive alternative to oil products as it is liquid, and hence, can be burned in conventional spark-ignition or compression-ignition engines. Moreover, methanol-fueled engines produce fewer emissions. However, methanol is toxic and corrosive, requiring special handling and storage facilities, and there is growing concern over methanol-fueled engines generating higher levels of noxious aldehydes. Compressed natural gas has been in use for some time as a transport fuel but also has serious drawbacks because of its gaseous nature. Storage is a problem, and emission of nitrogen oxides may be higher than for gasoline-fueled engines.

B. Conversion of energy flows

69. Man can draw upon very large continuing flows - and a finite stock - of energy. Indeed, the yearly flow of energy to the earth's surface from the sun, from within the earth and from the moon is about 75 times as large as the amount of energy extractable from the entire stock of fossil fuels and uranium, and about 11,000 times as large as annual human energy use at the present time.

70. There are four main channels for garnering the energy of the sun. The 80,000 TWY annual conversion of solar radiation to sensible heat provides the

source of what is commonly called solar energy ("incident solar" in table 3). The nearly 40,000 TWY annual evaporation - precipitation cycle, a tiny fraction of which is captured in rain and snow run-off, provides the basis for hydropower. Sun-induced temperature differentials in the seas and air lead to wind and wave energy potential of about 0.4 TWY per year. And the photosynthesis-oxidation cycle yields about 0.04 TWY of biomass energy each year.

71. In addition to solar radiation, the earth yields about 32 TWY of geothermal energy flow annually, and the moon provides another 3 TWY of tidal energy flow. 30/

72. Each of the major channels of solar flow, the earth's geothermal resources and the tidal power of the moon has been the focus of intensive technological scrutiny, especially since the oil price rises of 1973-1974 and 1979-1980. This research has led to the identification of many discrete technologies for tapping the energy contained in them. The technologies vary a great deal in terms of technical maturity, economic competitiveness and scale. (Many are electricity sources and must compete with conventional large-scale, relatively low-cost power sources, such as coal and nuclear in central power applications.) Unfortunately, space limitations prevent separate treatment of each, except for geothermal energy, in which the Economic and Social Council, in its resolution 1989/6, expressed an explicit interest. However, table 3 summarizes information on a number of the technologies. 31/

Table 3. Technologies of renewable energy

Technology	Energy form	Status
Sun:		
Incident solar:		
Passive heating	Heat (H)	Developed, usually economical, mixed deployment
Active heating	H	Developed, variable economics and development
Thermal electric	Electricity (E)	Developed, largely economical
Photovoltaic (PV)	E	Rapidly developing, varied projections
Solar ponds	E	Demonstrated, not economical at present
PV-hydrogen	Liquid fuel (F)	Components proven; economics speculative

Table 3 (continued)

Technology	Energy form	Status
Hydro:		
Large-scale	E	Developed, often economical, widely deployed
Micro-hydro	E	Developed, usually economical, not widely deployed
Wind:		
Pumping	Mechanical	Developed, deployed in remote areas
Onshore turbines	E	Recently developed, still improving, early deployment stage
Offshore turbines	E	Some trial stations, varied projections
Wave:		
Shore-based	E	Test stations, favourable results
Deep water	E	Wide variety of devices; pilots but no prototypes tested
Biomass:		
Organic residues	H	Widely used, but inefficient
Distillation, fermentation, etc.	F	Various demonstrated, usually not economical at present
Gasification	F, E	Unproven but promising
Earth:		
Geothermal		
Aquifers	H, E	Proven, often economical
Hot dry rock	H, E	Exploratory schemes, mixed results

Table 3 (continued)

Technology	Energy form	Status
Moon:		
Tidal		
Estuary dams	E	Proven; economics depend heavily on financing assumptions
Streams	E	Speculative

Source: Adapted from M. J. Grubb, "The Cinderella Options" (a study of modernized renewable energy technologies), Energy Policy, July/August 1990.

Note: Some other technologies of renewable energy include fusion, OTEC, dew-point energy, salt gradients, solar satellites.

Geothermal energy

73. The heat contained in the upper few kilometres of rock world wide is larger even than world uranium reserves employed in breeder reactors. Indeed, the earth spontaneously radiates about 32 TWY of heat from its surface over the course of a year, about three times the total annual energy use of man. For the foreseeable future a very small portion of even this lesser amount, concentrated in a relatively small number of discrete sites, can be captured and utilized.

74. Geothermal power at present depends mainly on the exploitation of hot brine-dominated aquifers (as opposed to steam-dominated, or hot rocks). The primary technologies employ closed or open steam cycles. In the former, hot brines are used to boil water in a separate circuit, the steam being used to turn a turbine to generate electricity. In the latter, wet steam from aquifers is first cleansed of impurities, pressurized and then employed directly in turbines.

75. It seems that the future exploitation of geothermal resources for either electric power or heat will be limited mainly by the site-specific nature of the resources themselves. Although unlikely to contribute even 1 per cent of the world's energy supply early in the next century, geothermal power may becopme (or remain) important for some countries, for example, El Salvador, Iceland, Kenya, Nicaragua and the Philippines. In some of these countries, geothermal resources may contribute as much as 20 per cent of energy supply.

III. THE ROLE OF PUBLIC POLICY

76. There is a role for public policy both in the shaping of the evolution of energy use intensities and in the translation of energy resource potential into actual production capacity. Policy towards either the use or production aspect of energy often has profound environmental consequences. The interrelationship between energy policy and environmental policy is explored in this section. In addition, the question of public measures towards augmentation of energy production capacity in developing countries is considered. The section concludes with a treatment of economic and technical co-operation among developing countries.

A. Energy and the environment

77. In order to understand precisely how energy policy and environmental policy intertwine, it will be useful to review how the concept of economic efficiency applies to the production and use of energy. It will then be possible to see how that idea, as applied to energy, naturally extends to incorporate environmental considerations.

Energy efficiency and energy markets

78. The goal of energy policy is to ensure that energy is produced and used at rates which are economically efficient from a social point of view. That is not to say that the efficiency thrust of energy policy should never be blunted by considerations of social equity, national independence or other overriding factors, but rather that the normal, abiding aim of policy is to enhance the economic efficiency with which energy is converted at all stages.

79. The idea of economic efficiency applies to both energy supply and energy demand. Energy is efficiently produced - in an economic sense - if the various energy forms and fuels are produced in quantities such that the social marginal costs and benefits of each are equal. The resulting production pattern is efficient in the sense that it maximizes the value of output of the energy sector as a whole. Similarly, the energy so produced is efficiently distributed - in an economic sense - if it is allocated such that in every employment, the value of its social marginal product and cost are equal. This distribution mix is efficient in that it maximizes the value of energy's contribution to aggregate economic output.

80. The world is witnessing an expanding recourse to market mechanisms as devices for approximating, in practice, the theoretical ideal of economically efficient allocation. As is well known, markets must yield prices which are free to change in response to shifts in supply and demand and must reflect a reasonable degree of competition on both sides, if they are to retain the advantages in terms of economic efficiency claimed for them. As regards energy markets, there is an obvious role for Governments to ensure that these qualities obtain in practice.

Cases of market failure

81. In spite of the general utility of free, competitive markets as allocative devices, there are situations in which they do not - even in principle - result in production levels or allocations in which social benefits and costs are equal. These cases of market failure arise under various sets of circumstances depending on the sectoral context. As regards energy, they occur most commonly in situations in which certain benefits (or costs) accruing to society as a whole are external to the economic calculations of private decision makers.

82. In the context of energy supply, situations arise in which the production of some energy form or fuel occasions the creation of a benefit to society at large which is not captured by the private producer of the energy, that is, its value is not reflected in the market price for the energy produced. Since the price does not incorporate the value of the external (as the producer sees it) benefit, the level of energy output will be too low from the point of view of society as a whole. An example sometimes cited is that of the small, local crude oil producer whose output is held below a social optimum because the price received for oil domestically does not reflect such external values as added energy security for the country and oil import bill reduction. On the other hand, there are occasions in which energy production gives rise to a cost to the society which is not incurred by the private energy enterprise. In this case, output is carried beyond the socially optimal level. Often, certain costs appear external to the private producer only because they have been made so by past public policy, that is, producers have been subsidized by the absorption of certain real costs of production by the society.

83. External benefits and costs also create discrepancies between social and private optima in the allocation of energy, once produced. More specifically, employment of a particular form of energy may create a benefit to society which is not appropriated by a private employer. The value of the marginal product of energy as seen by the private firm is less than the value viewed from a societal perspective, and actual utilization is held below its socially optimal level. For example, some view the production of renewable energy forms as conferring a benefit on the society in terms of security from the risk of disruption of imports of oil. In this case, subsidies to the producers of renewable energy are desirable in order to expand the output of such energy forms to the socially optimal level. Conversely, energy use may involve a cost paid by society but not by the private employer, leading to overuse. The classic example is coal utilization for electricity generation in secondary power plants. Coal burning produces environmental effects (sulphur and nitrogen oxide emissions, particulates and carbon dioxide) which are certainly costs to society but which do not appear as expenses on the books of the power plant.

84. The relationship between energy conversion and environmental degradation at the policy level is now clear. Energy conversion invariably involves environmental damage. Such damage, although a cost to society as a whole, falls outside of the profit-loss calculations of energy producers or users. The resulting market failure calls for governmental policy action to produce rates of production or employment of energy at which social costs (including environmental ones) and benefits are equal.

The policy response

85. Two broad classes of measures have been employed to correct perceived instances of energy market failure: attempts to internalize external benefits and costs and governmental mandates.

86. Socially incorrect levels of energy production or use occur when certain benefits or costs are not viewed as such by private decision makers. In principle, it should be possible to induce these decision makers to produce or use energy at socially optimal levels by adding to the price they receive as producers through subsidies, or adding to the price they pay as users through taxes. In other words, external benefits or costs are internalized to private producers or employers of energy. In the European Economic Community, the idea of internalization of external environmental costs is captured in the "Polluter Pays Principle". 32/

87. Governmental mandates in the energy field include regulations governing the energy-using behaviour of firms and individuals, and standards imposing minimal levels of energy conversion efficiency on durable goods, both producer and consumer. Both governmental regulations and standards seems to be rationalized on the same grounds as internalizing subsidies. There is a social benefit to employing more capital (labour, etc.) and a social cost to employing more energy. These are external to the decisions of individual employers of productive services. Therefore, capital (labour, etc.) is underemployed and energy over-employed. Mandates are then an attempt to set the actual rates of utilization of these services equal to their socially optimal rates by law.

88. The most important area of application within the environmental field of the principles discussed is global warming. The greenhouse gases released during fossil fuel use are costs to society as a whole, but external to the calculations of individual users, whether private or governmental. Fossil fuels are produced and employed at rates exceeding social optima, and public policy is needed to reduce both. The policy means most frequently mentioned to achieve this end is internalization of the external costs of fossil fuels through imposition of a tax on the carbon content of the fuels employed, a so-called "carbon tax".

B. Production capacity expansion in developing countries

89. There is almost universal agreement that developing countries will need higher levels of energy conversion in the future if they are to sustain higher levels of GDP. Even if elimination of waste and substitution of capital for energy progresses more rapidly than the shift in the product composition of aggregate output in these countries (so that energy intensity falls), higher absolute output will demand higher absolute energy input. There are only two sources of the incremental energy required: increases in energy imports or expansion of domestic energy production capacity. For most developing countries, this will not be an "either/or" choice. A reasonable regard for the principle of comparative advantage will dictate a large expansion of energy imports; nevertheless, many opportunities for the economic augmentation of existing energy production capacity will also exist.

90. The main obstacle to the transformation of energy resources into production capacity in developing countries is the problem of financing the required investment. The fundamental reason for the existence of the problem, of course, is underdevelopment itself - levels of per capita income so low that when minimal consumption needs are satisfied, little or nothing is left for savings. The effects of this basic condition on energy resource finance are magnified by the very nature of energy investment. Cash flows "up front" are usually negative and large, and the whole projected cash flow stream is often subject to great uncertainty. For example, in the case of oil exploration, the present value of the cash flow stream can range from negative and large to positive and large, depending on whether commercial quanitities of oil are assumed to be found or not. There are, however, several steps which can be taken at the national or international level to mitigate the effects of these factors on the expansion of energy production capacity.

91. Perhaps the most important of these is for Governments to permit domestic energy enterprises - both public and private - to enlarge, and retain a greater portion of, their net cash flows. Ideally, expansion of production capacity by an enterprise is self-financed. Cash provided by net income and depreciation allowances is retained within the enterprise to pay for new (and replacement) capacity. However, if the price of energy sold by the enterprise if fixed by law at below market-clearing levels, net income is depressed, and less cash is available for all purposes. Petroleum product prices or electricity tariffs frequently fall in this category in developing countries, and the national oil companies or public utilities of the countries concerned suffer in terms of their capacity to finance their own expansion. (In the case of electrical utilities, this happens frequently in developed countries too.) Net income is adversely affected by unnecessarily high costs as well. For example, feather-bedding is a problem in some national energy companies. Similarly, "local sourcing" laws, which require enterprises to purchase certain equipment or supplies from domestic sources even though higher in price than those available abroad, can raise costs to these enterprises. Finally, when cash does begin to accumulate in domestic energy companies, a reasonable proportion of it needs to be retained in the companies to finance expansion, rather than being surrendered to national treasuries in the form of taxes or dividends.

92. Steps towards deepening capital markets in developing countries and making them more efficient would also facilitate the financing of energy investment. In cases in which internal financing of expansion by energy enterprises was impossible, a smoothly functioning capital market might provide an alternative source of funds. Reforms, such as the provision of deposit insurance, the indexation of some interest rates and the creation of terminal exchanges for the trading of financial instruments, inter alia, could help create such markets in many countries. It should be noted, however, that successful market financing by energy enterprises in developing countries depends to a considerable extent on the same objective conditions as successful self-financing. Debt service or dividends associated with market finance normally draw upon the same cash sources as self-financing. Government guarantees of debt service on the obligations of public or private energy companies would reduce the interest costs of such issues and facilitate their marketing.

93. Foreign equity participation also provides an avenue for the flow of funds to energy enterprises in developing countries. The main exemplar of this approach in the past has been foreign oil companies' participation in the exploration and development of the petroleum resources of developing countries. Such participation remains a possibility for developing countries which offer good geologic prospects for oil discoveries. Over the last decade, a number of countries have liberalized petroleum laws and softened the terms of exploration and development agreements in efforts to attract foreign risk capital. 33/ Other modalities for the utilization of foreign capital have evolved in recent years. For example, B.O.T. schemes, in which coal exporters and power plant manufacturers from developed countries Build, Operate, and then Transfer electricity-generating facilities to developing countries, have apparently proven successful in several cases.

94. Finally, there is an obvious role for the international and national development institutions to play in the financing of new energy production capacity in developing countries. In the report of the Secretary-General on the development of the energy resources of developing countries (A/39/420), submitted to the General Assembly in 1984, it was estimated that the average annual shortfall between the energy financing requirements of developing countries and sums likely to be forthcoming from traditional financing sources (internal cash generation, domestic capital markets and foreign direct investment) to be on the order of $30 billion (1982 dollars) over the last 18 years of the century. Unfortunately, the last six years do not seem to have provided any sound reason to reduce that figure. With the combined energy spending of the international and national development agencies well below $30 billion (1982 dollars) per year, budgets need to be substantially augmented if economic growth rates in developing countries are not to stagnate at unsatisfactory levels.

C. Co-operation among developing countries

95. Further expansion of economic and technical co-operation among developing countries in the area of efficiency improvement is highly desirable. Numerous examples of such co-operation in enhancing efficiency on the supply side already exist. For example, the Regional Association of State Petroleum Enterprises of Latin American Countries has been an effective instrument of technology transfer among the participating national oil companies. Meetings of experts are held several times a year under the responsibility of a member national oil company. The results of these meetings have been very encouraging, as they have not only provided a channel for dissemination of scientific and technical knowledge but also for the exchange of practical experience. Similarly, the Organization of Petroleum Exporting Countries and the Organization of Arab Petroleum Exporting Countries, in addition to providing forums for co-ordination of members' oil policies, also provide opportunities for technical exchanges.

96. Efficiency in energy use has also come to be a leading concern of the various regional arrangements in energy among developing countries. For example, the Latin American Energy Development Organization provides co-ordination and advisory services for the integration and rational utilization of the region's energy resources, and serves as a focal point of co-ordination of energy planning in the region as a whole. Similar services are provided by the Association of South East

Asian Nations (ASEAN) Council on Petroleum for South-East Asia and by the African Petroleum Producers Association for Africa. Expansion of such efforts, for example, to the practical demonstration of new energy efficient capital goods for industry, would be valuable. The demonstration phase - beyond research and development - has proven to be crucial in moving efficiency improvements from the laboratory to widespread practical application.

Notes

1/ This is the intensity of use in the production of goods and services. An analogous intensity of energy use in direct consumption can be defined as energy used per meal cooked, or per square metre per degree-day of housing heated, or per kilometre driven.

2/ See the discussion in Jose Goldemberg and others, "An end-use oriented global energy strategy", Annual Review of Energy, vol. 10 (1985), pp. 613-688.

3/ M. Ross and others, Energy Demand and Materials Flows in the Economy (Princeton, N.J., Princeton University, Centre for Energy Environmental Studies, report number 193, 1985).

4/ 10^9 joules.

5/ G. J. Hare and others, A Preliminary Overview of Innovative Industrial Materials Processes (Richland, Washington, Battelle Memorial Institute, September 1983).

6/ Industrial Energy Requirements: Potential for Conservation (B.I.A.C. Committee on Energy and Raw Materials, November 1983).

7/ Amory B. Lovins and others, The State of the Art: Drivepower (Snowmass, Colorado, Rocky Mountain Institute, April 1989).

8/ Deborah L. Bleviss, "The Role of the Automobile", Energy Policy, March 1990, pp. 137-148.

9/ Jose Goldemberg and others, Energy for a Sustainable World (Washington, D.C., World Resources Institute, September 1987), p. 7.

10/ For a full discussion see Jayant Sathaye and others, An End-use Approach to Development of Long-term Energy Demand Scenarios for Developing Countries (Berkeley, California, University of California, Lawrence Berkeley Laboratory, February 1989), pp. 11-17.

11/ M. Fraser, "Survey of the applications of solar thermal energy to industrial process heat" ("Sharing the Sun" Conference, International Solar Energy Society, Winnipeg, 15-20 August 1976).

Notes (continued)

12/ 10^{12} watt-years.

13/ World Energy Conference, 1989 Survey of Energy Resources (London, World Energy Conference, 1989), pp. 46-47.

14/ N. Boy de la Tour, J. L. Gadon, and J. J. Lacour, "New oil: what's in the future?", Energy Exploration and Exploitation (Barking, United Kingdom), Elsevier Applied Science Publishers Ltd., vol. 4, No. 6 (1986), p. 449.

15/ R. F. Meyer and C. J. Schenk, An Estimate of World Resources of Heavy Crude Oil and Natural Bitumen (Third UNITAR/UNDP International Conference on Heavy Crude and Tar Sands, 1985).

16/ World Energy Conference, op. cit., p. 57.

17/ N. Boy de la Tour and others, op. cit., p. 461.

18/ World Energy Conference, op. cit., pp. 16-17.

19/ Ibid.

20/ The World Bank quoted in Coal Age, April 1986, p. 29.

21/ Ibid.

22/ India, Coal Mining and Coal Quality Improvement Project, report No. 5843-IN (Washington, D.C., The World Bank, 25 March 1987).

23/ Coal Utilization (UNESCO, 1983).

24/ World Energy Conference, op. cit., pp. 64-65.

25/ Ibid.

26/ Petroleum Economist, August 1990, p. 9.

27/ Ibid.

28/ Ibid., p. 11.

29/ Oil and Gas Journal, 26 February 1990, p. 29.

30/ Data on major energy flows from: Phillip G. Le Bel, Energy Economics and Technology (Baltimore, Maryland, The Johns Hopkins University Press, 1982), pp. 79-87.

Notes (continued)

31/ The Secretariat has produced a number of reports dealing with renewable energy forms. See, in particular, the series A/AC.218/1990/2 to A/AC.218/1990/8, prepared for the Fifth Session of the Committee for the Development and Utilization of New and Renewable Sources of Energy.

32/ OECD and the Environment (Paris, Organisation for Economic Co-operation and Development, 1986), p. 20.

33/ Ibid., p. 20.